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TECHNICAL NOTE

No. 1271

AXIAL-FLOW FAN AND COMPRESSOR BLADE DESIGN DATA

AT 52.5° STAGGER AND FURTHER VERIFICATION

OF CASCADE DATA BY ROTOR TESTS

By Seymour M. Bogdonoff and Eugene E. Hess

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

Washington

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SUMMARY

Previous tests of blower-blade sections have been extended by a
series of tests at 52.5° stagger. The results of these tests have
been combined with the earlier test results and are presented in new
blade design charts which supersede those previously presented. An
investigation in a test blower over a range of stagger from 44°
to 65° has shown that for blades at a solidity of 1.0, the two-
dimensional cascade data predict the turning angle to within 1/2°.

INTRODUCTION

The two-dimensional cascade investigation of reference 1 covered
a series of tests of blower-blade sections at staggers of 45° and 60°
and solidities of 1.0 and 1.5. In an attempt to increase the
accuracy of the design charts of reference 1 and to obtain a measure-
ment of their precision, additional cascade tests were conducted
at 52.5° stagger on the NACA 65-410, 65-810, and 65-(12)10 blower-blade
sections at solidities of 1.0 and 1.5 and tests were made in a test
blower to obtain performance data in an actual rotating setup. Some
of the performance data obtained from these rotor tests are reported
in reference 2. Information on performance of blade sections over a
range of stagger angle is presented herein and the results are com-
pared with predictions from stationary-cascade tests.

The cascade tunnel, test blower, and techniques and procedures
used in this investigation were the same as those described in
references 1 and 2. Data on the rotating blades, however, will be
presented only for the pitch section (where the flow is essentially
two-dimensional and the solidity equals 1.0). All symbols used are
the same as those in references 1 and 2.

PRESENTATION OF DATA AND DISCUSSION

Stationary two-dimensional cascade.- The pressure distributions
over the center blade of each of the cascades of NACA 65-410, 65-810,
and 65-(12)10 blower blades at a stagger of 52.5° and solidities
of 1.0 and 1.5 are presented in figures 1 to 6. The design point,
the angle of attack at which an essentially flat pressure distribution
was obtained, is indicated on each figure. The results of the
turning-angle investigations of the three blades are presented in
figures 7 and 8.

Reference 1 presents the following simple equation for the
prediction of turning angles in the range tested:

$$\theta = k\left(\alpha - \alpha_{l_o}\right)$$

where

θ turning angle

α angle between entering air and chord line

α_{l_o} angle of zero lift of isolated airfoil

k empirical constant determined from cascade tests

The value of k for 52.5° stagger is included with the previous
results of reference 1 in the following table:

Stagger (deg)	Solidity	k
45	1.0	0.90
45	1.5	1.00
52.5	1.0	.85
52.5	1.5	.95
60	1.0	.75
60	1.5	.90

These empirical constants and the approximate zero lift angle
(calculated as in reference 1) can be used to predict turning angles
in the range of the investigation to within approximately 1°.

The results of the rotor tests, presented in the section entitled "Test-blower results," seemed to show that the original data obtained for the NACA 65-(12)10 blower blade at a stagger of 60° and a solidity of 1.0 were not valid. A retest of this blade showed an increase in turning angle of approximately 2° and these data are presented in figure 9 with the results for the other blade sections from reference 1. The pressure distributions over the center blade of the cascade of NACA 65-(12)10 sections are presented in figure 10.

The very high loadings of the NACA 65-(12)10 blade (the highest of any tested in cascade) appear to present a limit beyond which the cascade-tunnel data are questionable. Very slight changes in tunnel adjustment may stall the tunnel walls, which seriously changes the blade performance. For this reason, the data for the NACA 65-(18)10 blade at this condition (60° stagger and solidity of 1.0) have been eliminated and figure 9 now supersedes figure 7 of reference 1.

Curves from reference 1 which are of interest in compressor design are repeated in figures 11 to 13 with the 52.5° stagger condition included. Figures 14(a) and 14(b) present the new blade design charts which include the data of reference 1. These charts supersede figures 41(a) and 41(b) of reference 1 and with the new and corrected data give more precise blade design information. If the design turning angle and entrance conditions are known, the blade camber and angle of attack can be found from these charts. A horizontal line may be drawn from the value of turning angle desired on the angle scale to intersect the turning-angle curves. A horizontal interpolation for stagger may be made along this line and from this point a vertical line may be drawn. The intersection of this line with the horizontal scale gives the design camber of the blades, and the intersection with the angle-of-attack curves, with a vertical interpolation for stagger, gives the angle of attack read on the angle scale. The procedure may be reversed to obtain the design turning angle if camber and design angle of attack are known. In order to obtain design data at solidities other than 1.0 and 1.5, the procedure is carried out at solidities of 1.0 and 1.5 and the final result obtained by interpolation.

Test-blower results.- The results of tests of four sets of blades in a single-stage test blower are presented in reference 2. One of the blades tested had an NACA 65-710 blower-blade section and a second blade had an NACA 65-(11)10 section at their respective pitch sections. (Blades designated as $\delta = 0.4$ and $\delta = 0.6$ in reference 2.)

In addition to the previous tests, the $\delta = 0.6$ blade was tested at two other angle settings which effectively gave design points at different staggers. The results of turning angle plotted against stagger, at 2° increments in angle of attack, are presented in figures 15 and 16. The test points are in very good agreement with the solid lines predicted from cascade tests. The deviation from predicted values is less than $1/2^\circ$ for most cases and shows the accuracy of the cascade results from staggers of 44° to 65°.

For cases in which the axial velocity changes through the blade, in reference 1 a modified vector diagram based on the average axial velocity was used for the blade design. Tests of two blades which were designed for just such conditions were made in the Langley propeller research tunnel. These tests show that for changes in axial velocity of the magnitude studied (30 percent of the entrance velocity), the cascade data could be applied with good accuracy.

CONCLUDING REMARKS

Previous tests of blower-blade sections have been extended by a series of tests at 52.5° stagger. The results are summarized in new blade design charts which supersede those of NACA ACR No. L5F07a.

Cross plots of data obtained from a test blower show that, over a range of stagger from 44° to 65°, turning angles predicted from cascade tests are within $1/2^\circ$ of those obtained from tests with a rotating setup.

Langley Memorial Aeronautical Laboratory
        National Advisory Committee for Aeronautics
            Langley Field, Va., May 29, 1946

REFERENCES

1. Bogdonoff, Seymour M., and Bogdonoff, Harriet E.: Blade Design Data for Axial-Flow Fans and Compressors. NACA ACR No. L5F07a, 1945.

2. Bogdonoff, Seymour M., and Herrig, L. Joseph: Performance of Axial-Flow Fan and Compressor Blades Designed for High Loadings. NACA TN No. 1201, 1947.
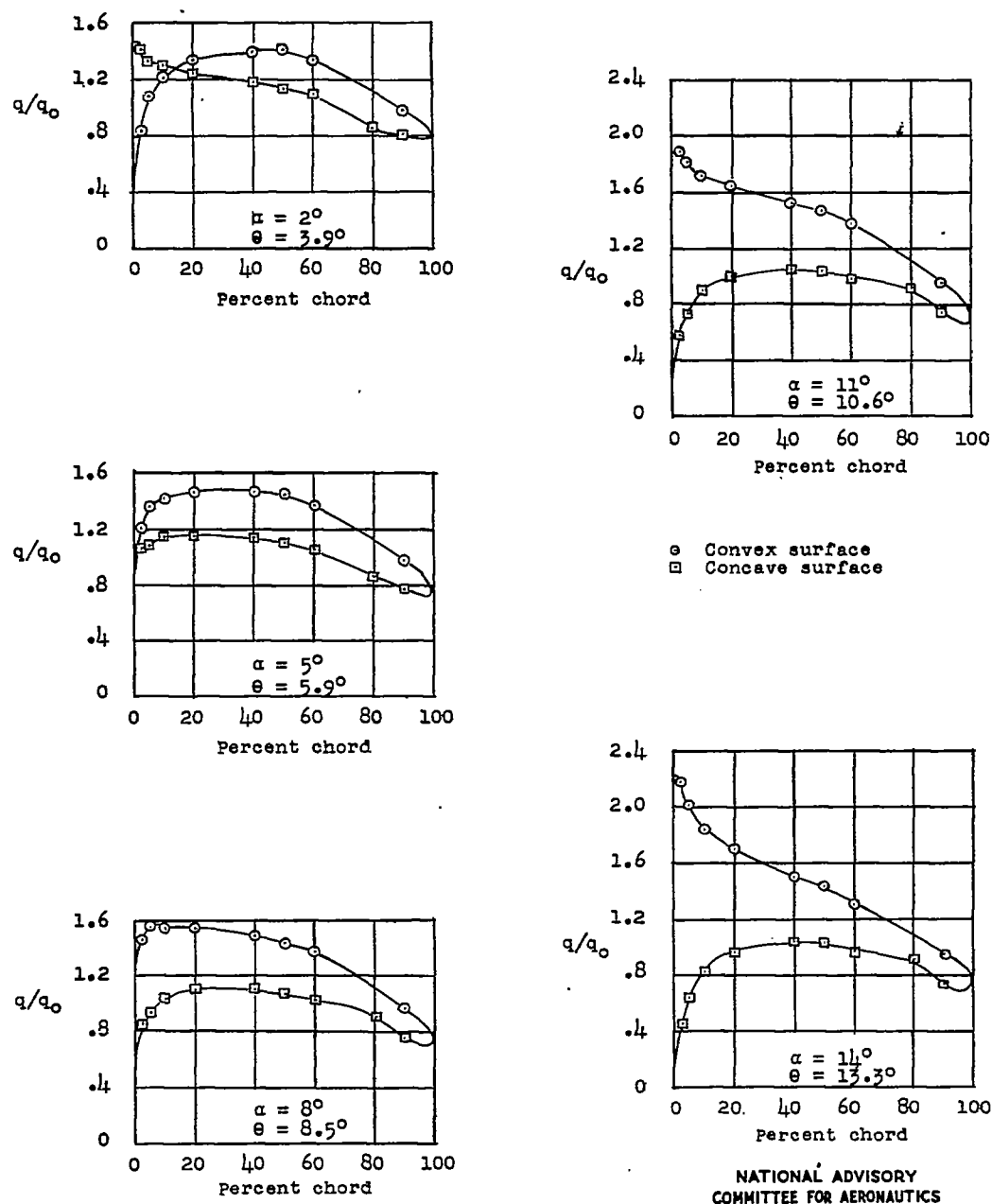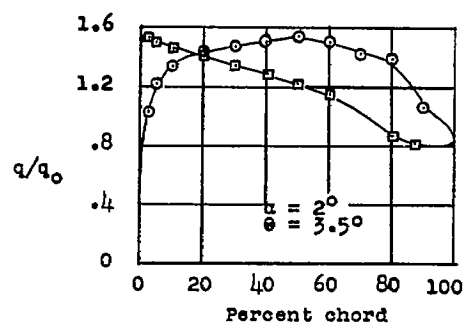
Figure 1.- Section pressure distributions. Cascade
of NACA 65-410 blower-blade sections; β = 52.5°;
σ = 1.0; α_d = 7.5°.

Fig. 2   NACA TN No. 1271
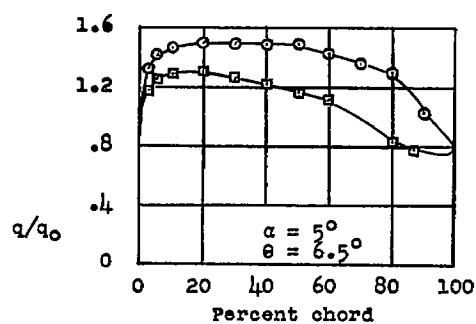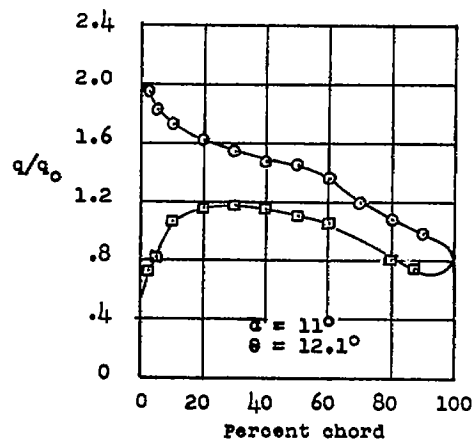
o Convex surface
▣ Concave surface
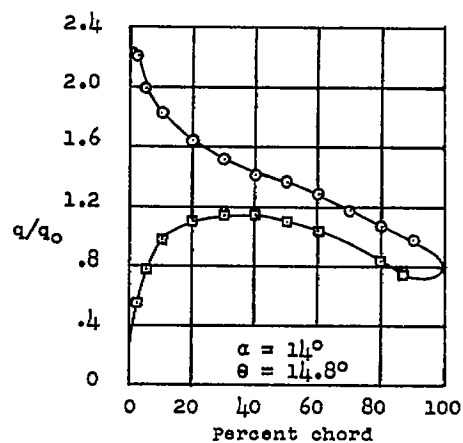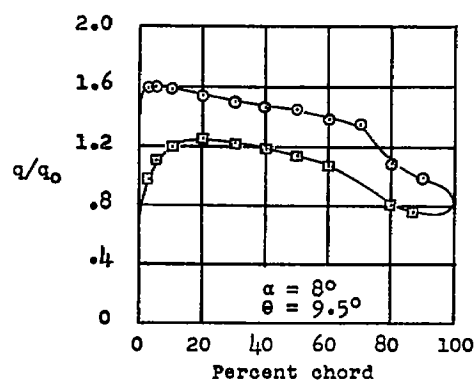
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Figure 2.- Section pressure distributions. Cascade
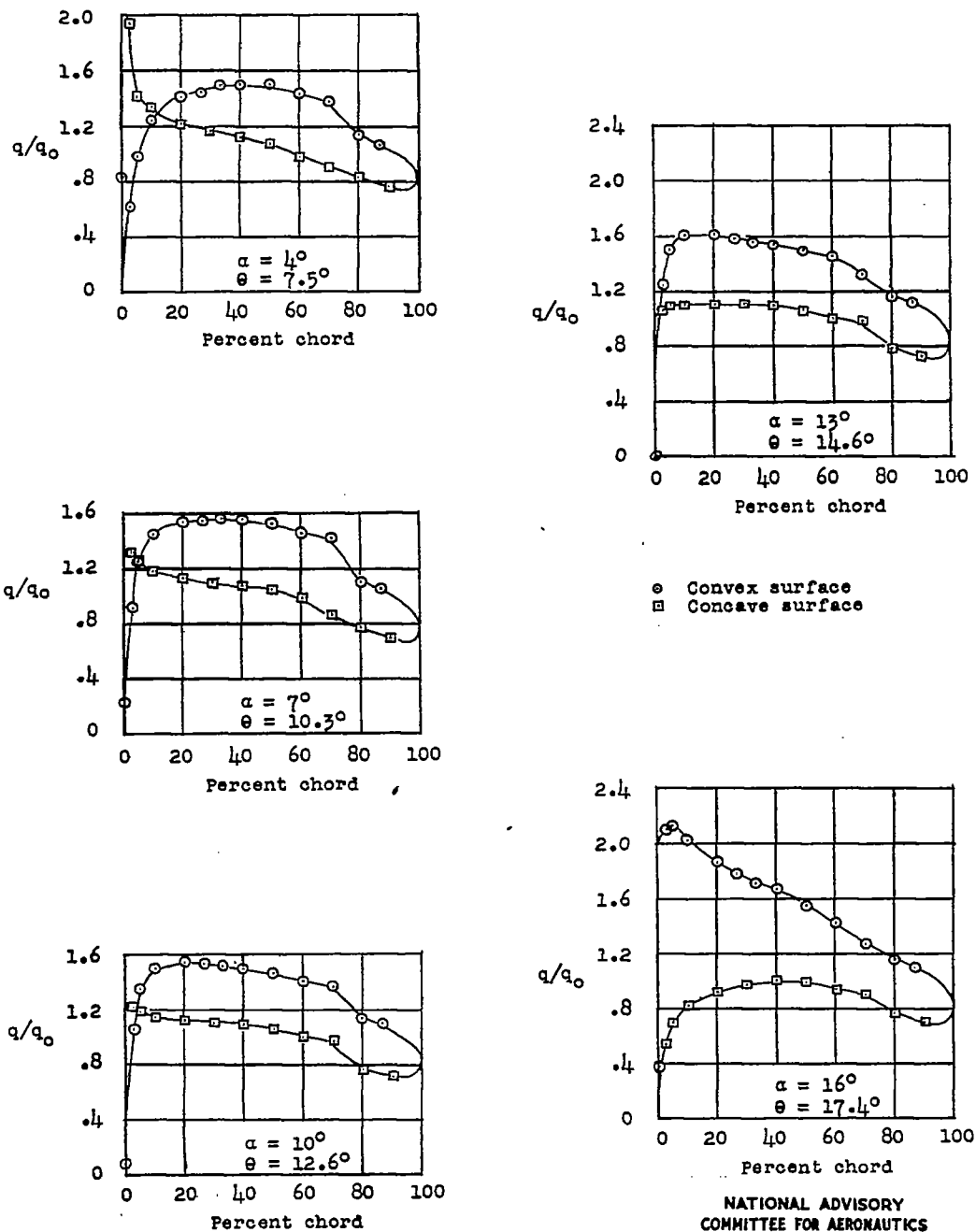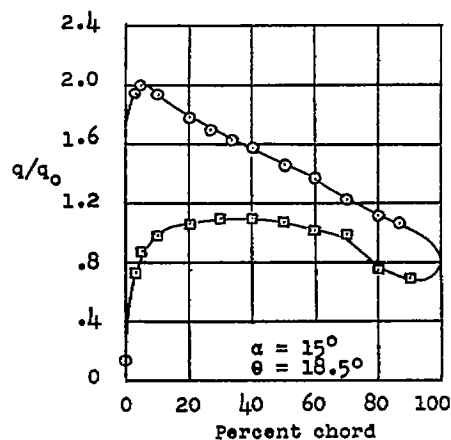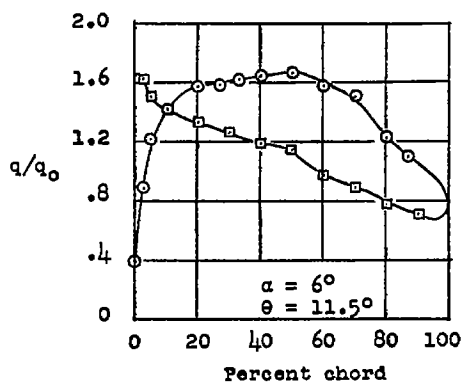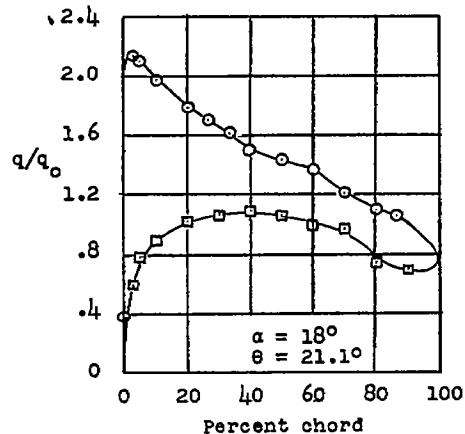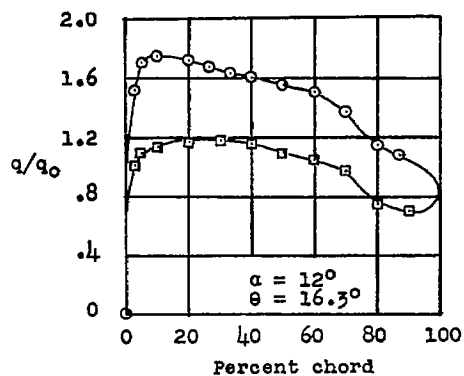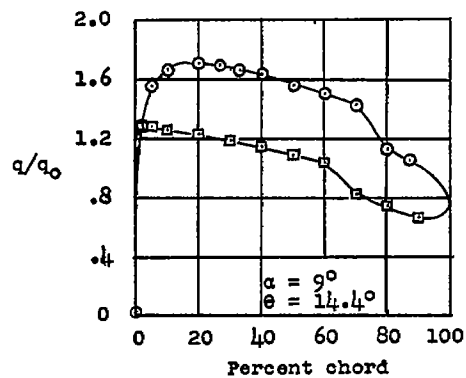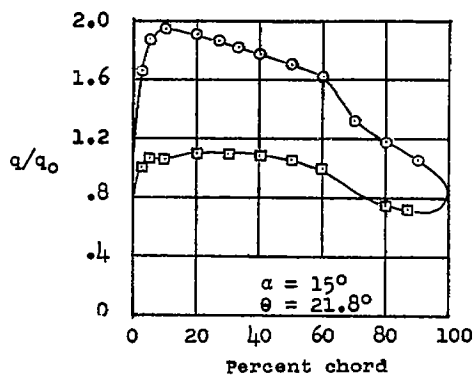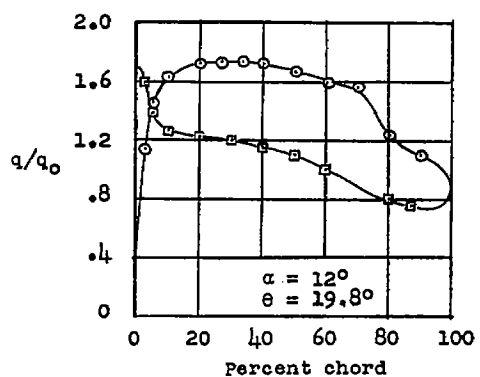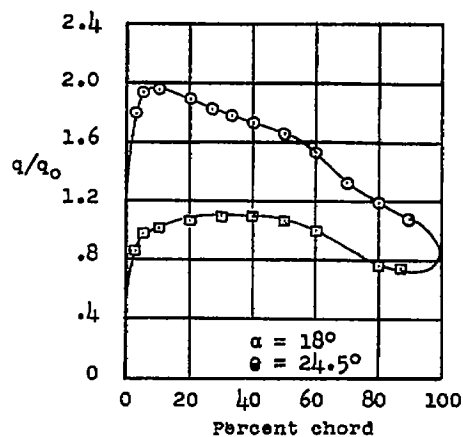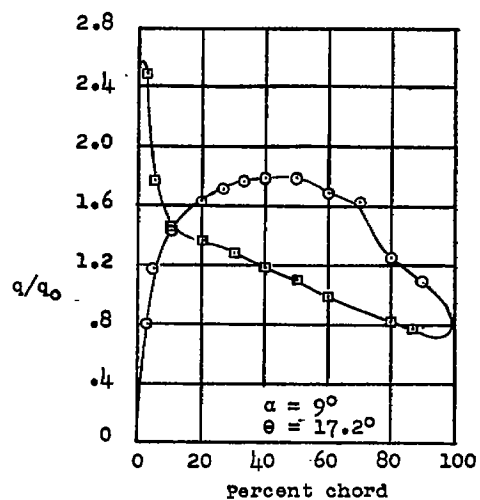of NACA 65-410 blower-blade sections; β = 52.5°;
σ = 1.5; a_d = 7.1°.

Convex surface
Concave surface

Figure 3.- Section pressure distributions. Cascade of NACA 65-810 blower-blade sections; β = 52.5°; σ = 1.0; α_d = 11.5°.

Fig. 4   NACA TN No. 1271

$\alpha = 6^\circ$
$\theta = 11.5^\circ$

q/q_o

Percent chord

$\alpha = 9^\circ$
$\theta = 14.4^\circ$

$\alpha = 12^\circ$
$\theta = 16.3^\circ$

$\alpha = 15^\circ$
$\theta = 18.5^\circ$

$\alpha = 18^\circ$
$\theta = 21.1^\circ$

⊘ Convex surface
▣ Concave surface

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Figure 4.- Section pressure distributions. Cascade
of NACA 65-810 blower-blade sections; $\beta = 52.5^\circ$;
$\sigma = 1.5$; $\alpha_d = 11.8^\circ$.

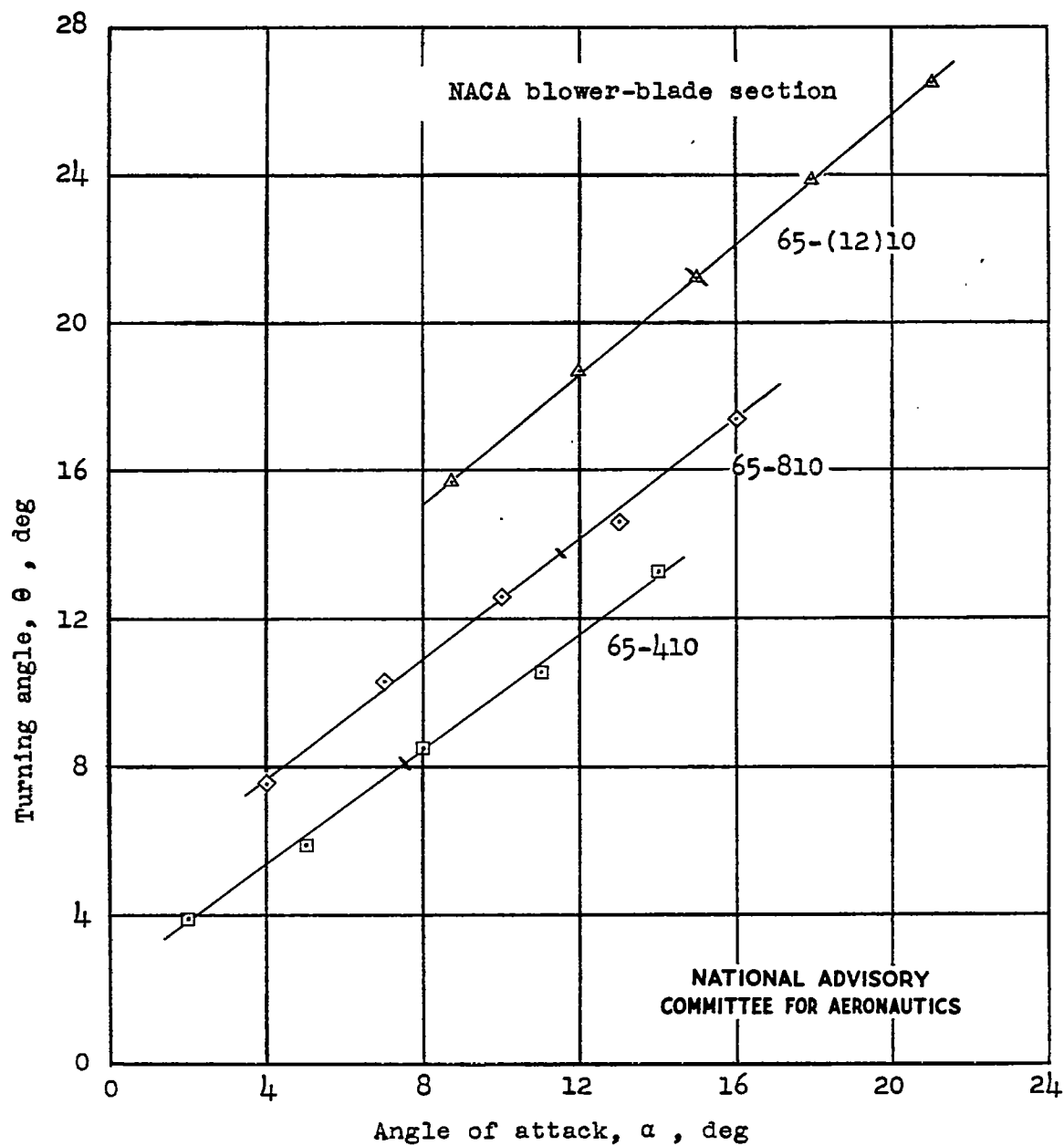○   Convex surface
□   Concave surface
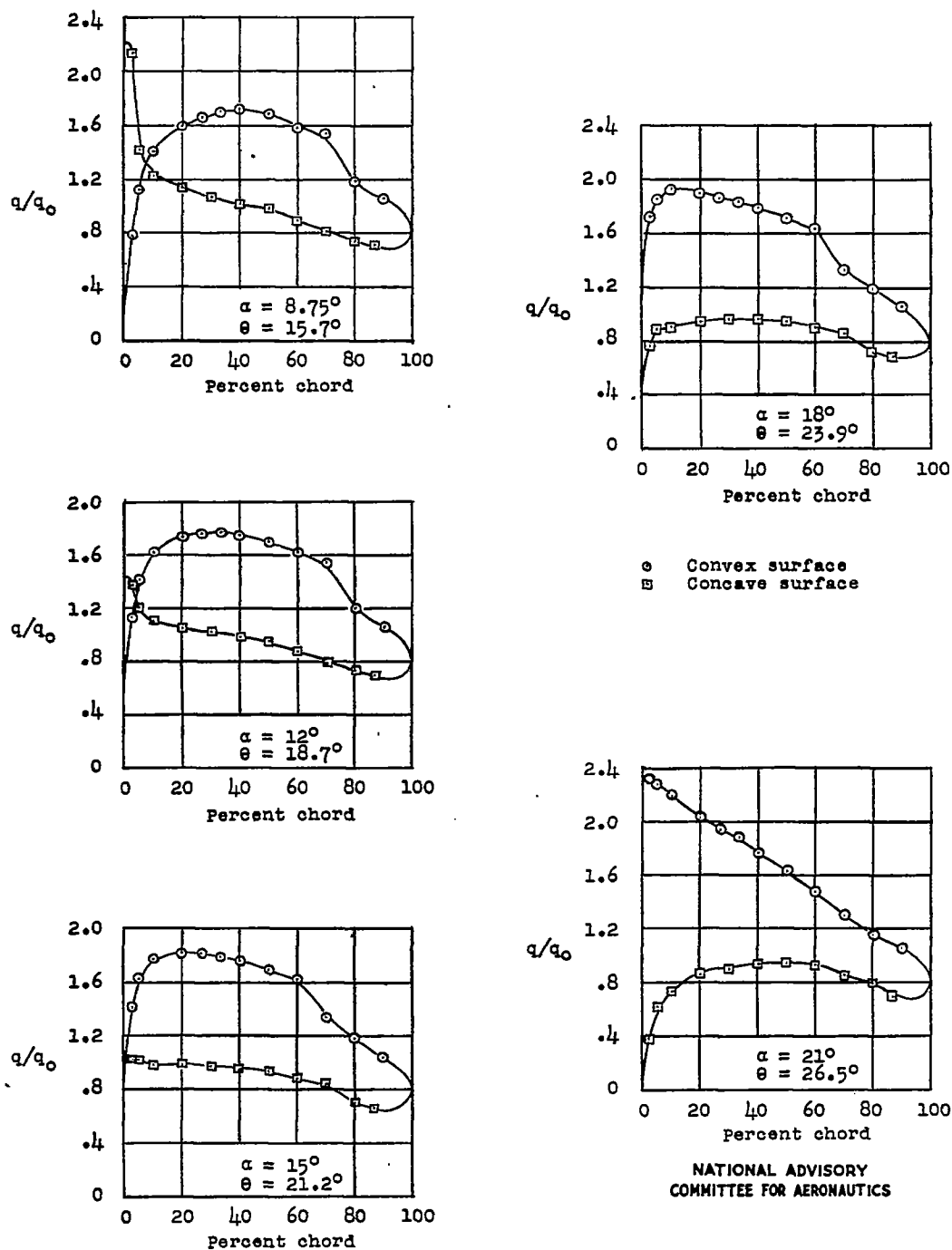
Figure 5.- Section pressure distributions. Cascade
of NACA 65-(12)10 blower-blade sections; β = 52.5°;
σ = 1.0; α_d = 15.0°.

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Fig. 6   NACA TN No. 1271

o Convex surface
▣ Concave surface
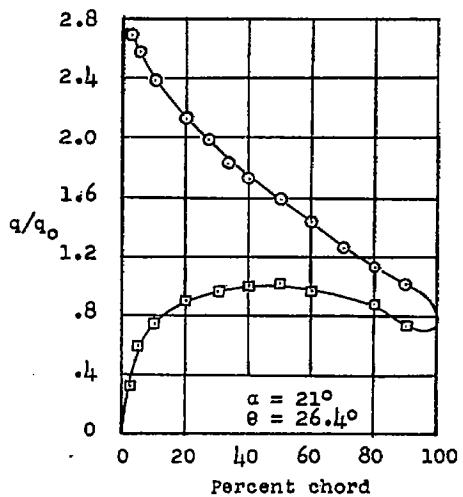
Figure 6.– Section pressure distributions. Cascade of
NACA 65–(12)10 blower-blade sections; $\beta = 52.5°$;
$\sigma = 1.5$; $\alpha_d = 16°$.

Figure 7.- Turning-angle characteristics. $\beta = 52.5°$;
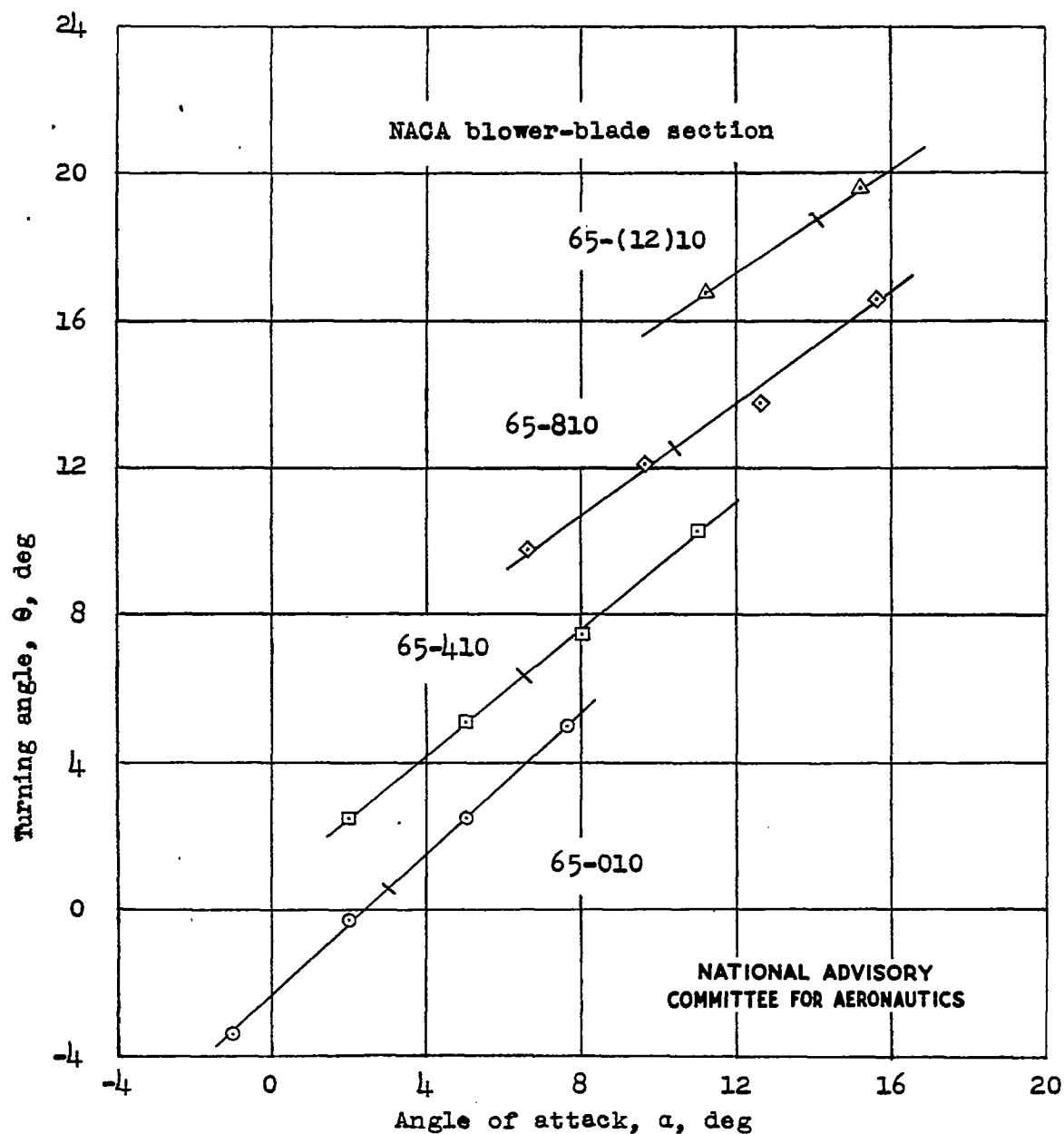$\sigma = 1.0$.   (Short line across curve is design point.)

Fig. 8   NACA TN No. 1271
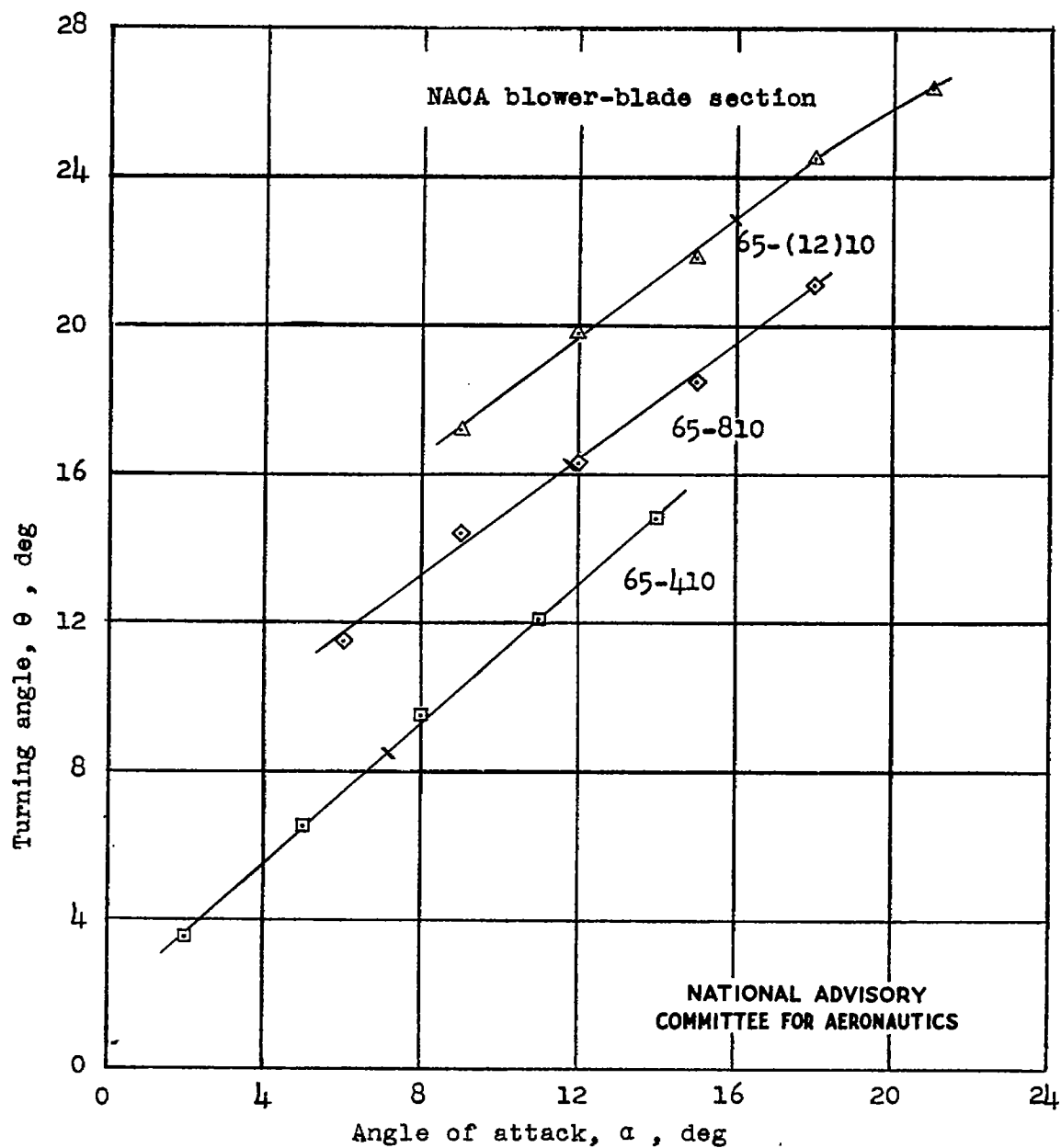
Figure 8.- Turning-angle characteristics. $\beta = 52.5°$;
$\sigma = 1.5$.   (Short line across curves is design point.)

Figure 9.- Turning-angle characteristics, including retest
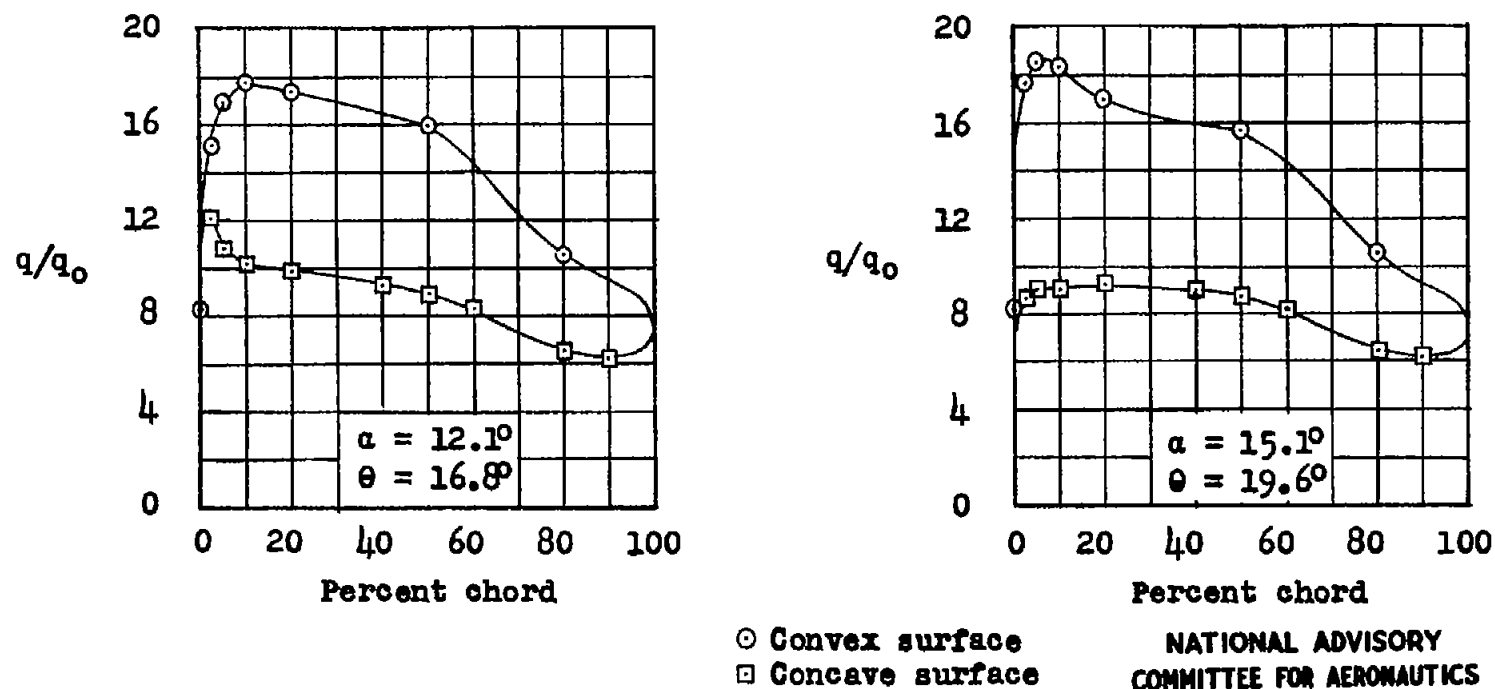of NACA 65-(12)10 section. β = 60°; σ = 1.0. (Short
line across curve is design point.)

Fig. 10

Figure 10.- Section pressure distribution. Retest of cascade of NACA 65-(12)10 blower-blade sections. $\beta = 60^{\circ}$; $\sigma = 1.0$; $a_d = 14.1^{\circ}$.
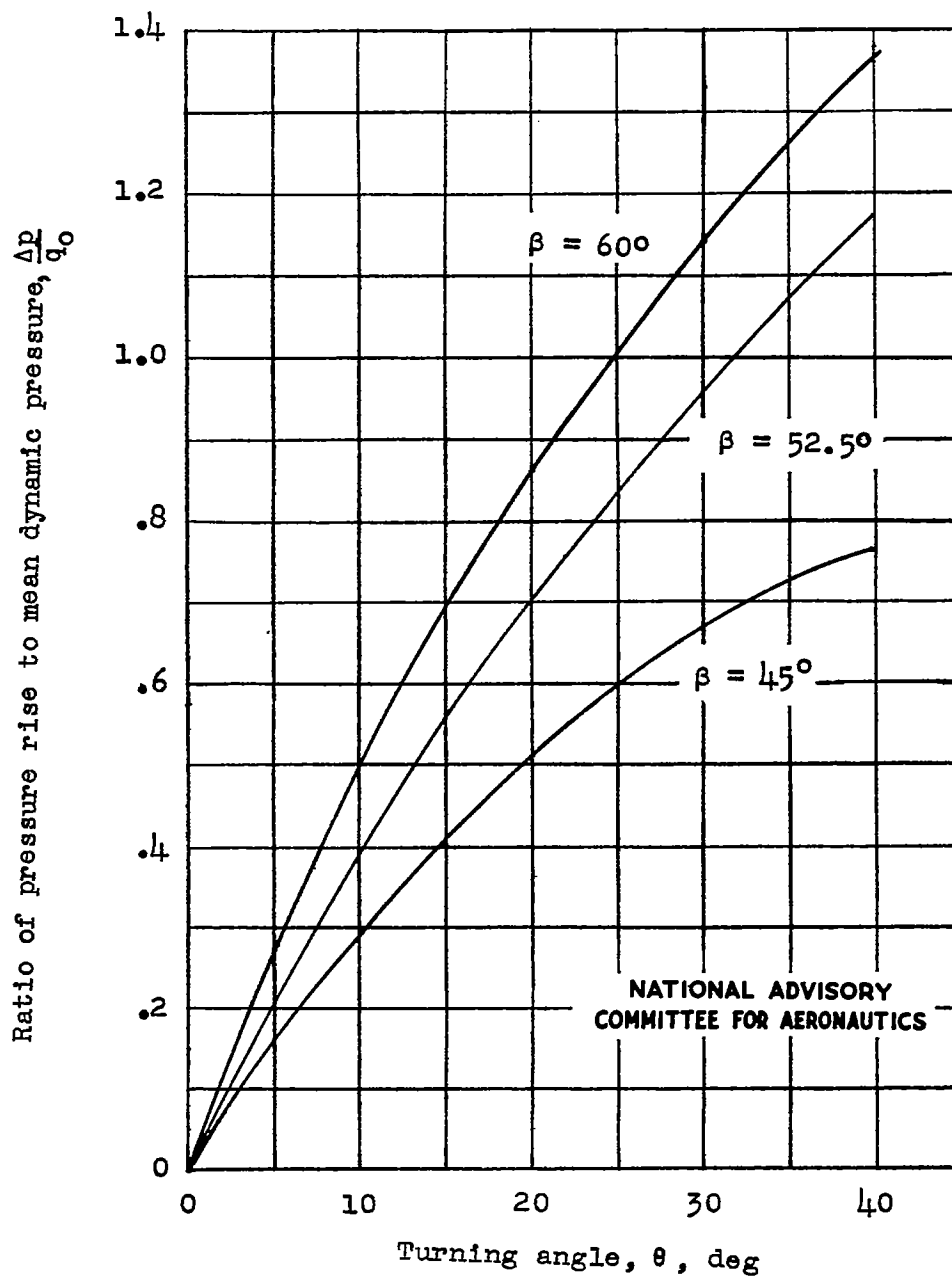
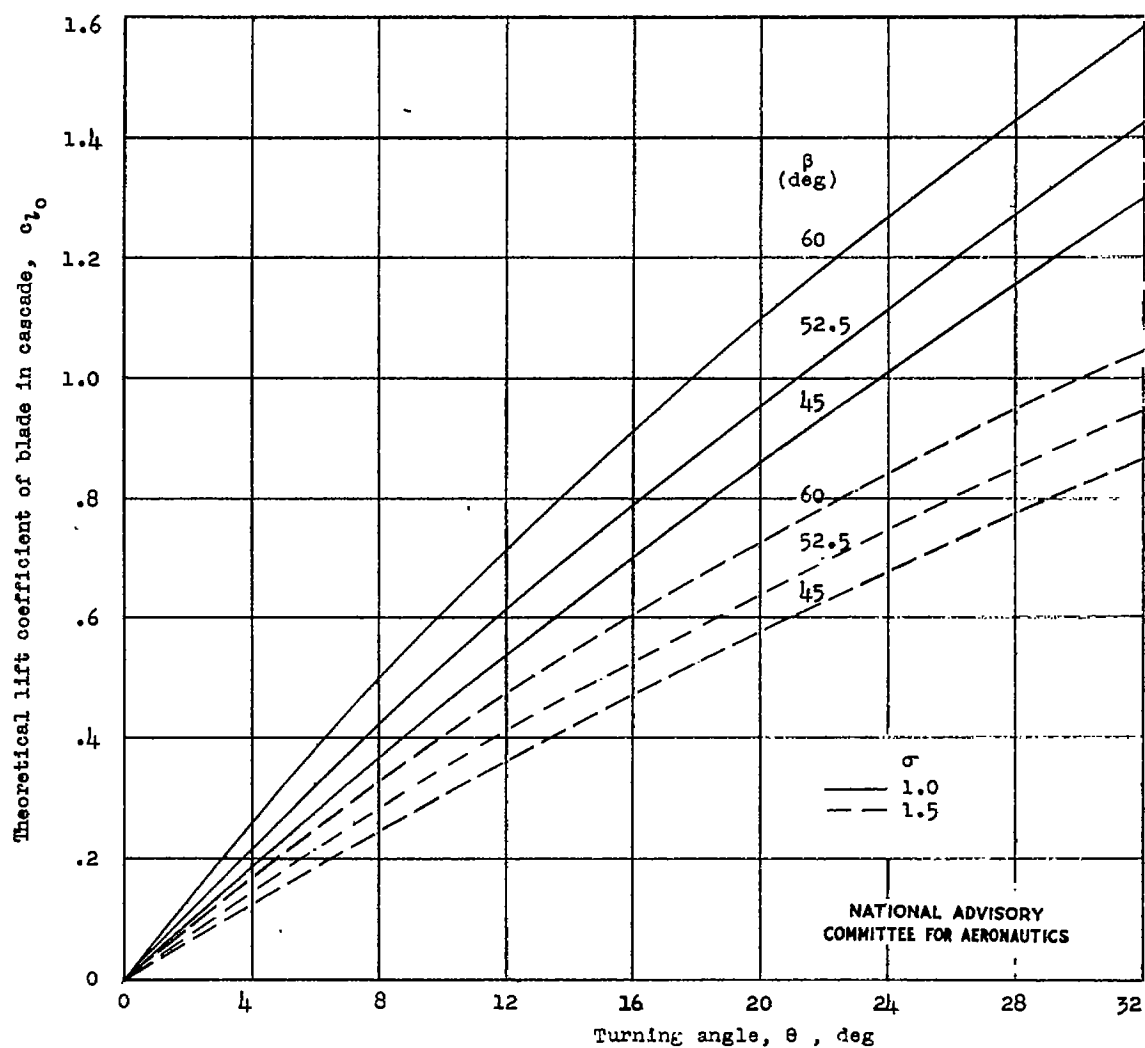Figure 11.- Variation of theoretical $\Delta p/q_o$ with turning angle for three stagger angles.

Fig. 12   NACA TN No. 1271

Figure 12.- Variation of theoretical lift coefficient of blade
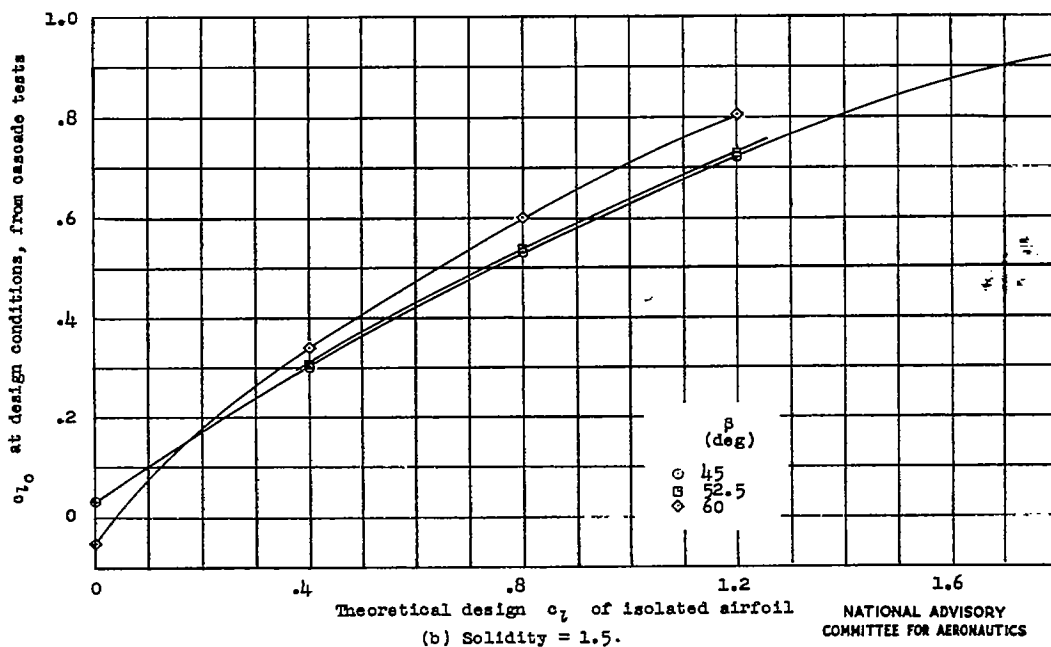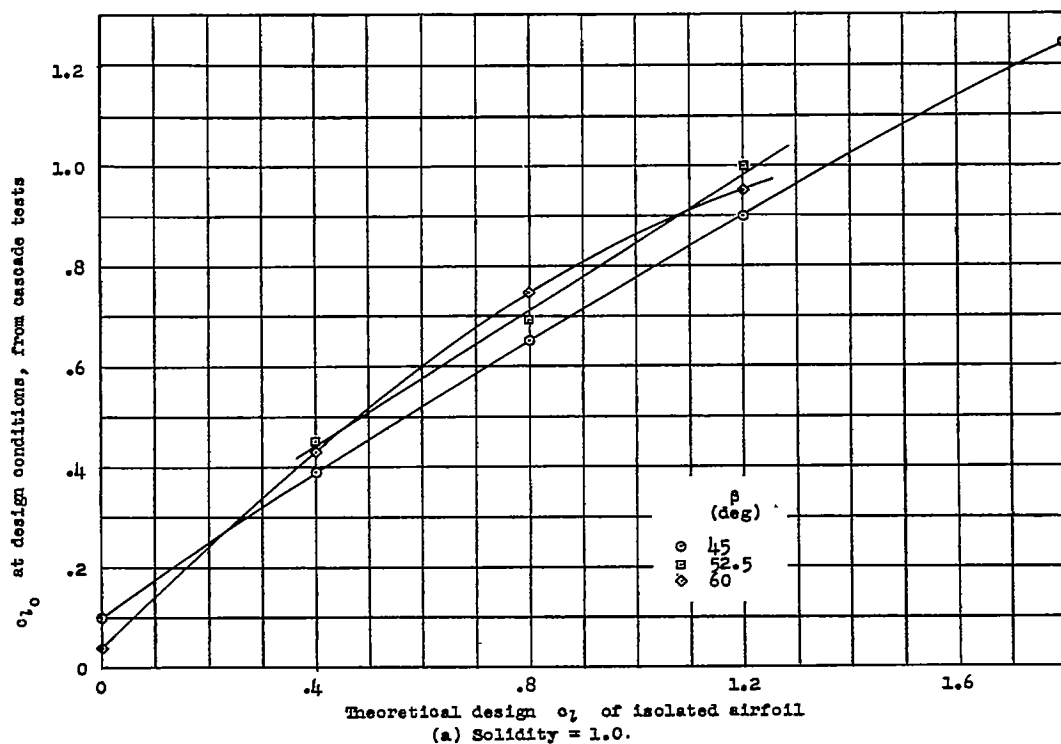in cascade with turning angle for various cascade configurations.

Figure 13.- Comparison of c_{l_o} of blade in cascade at design conditions with theoretical design c_l of isolated airfoil.
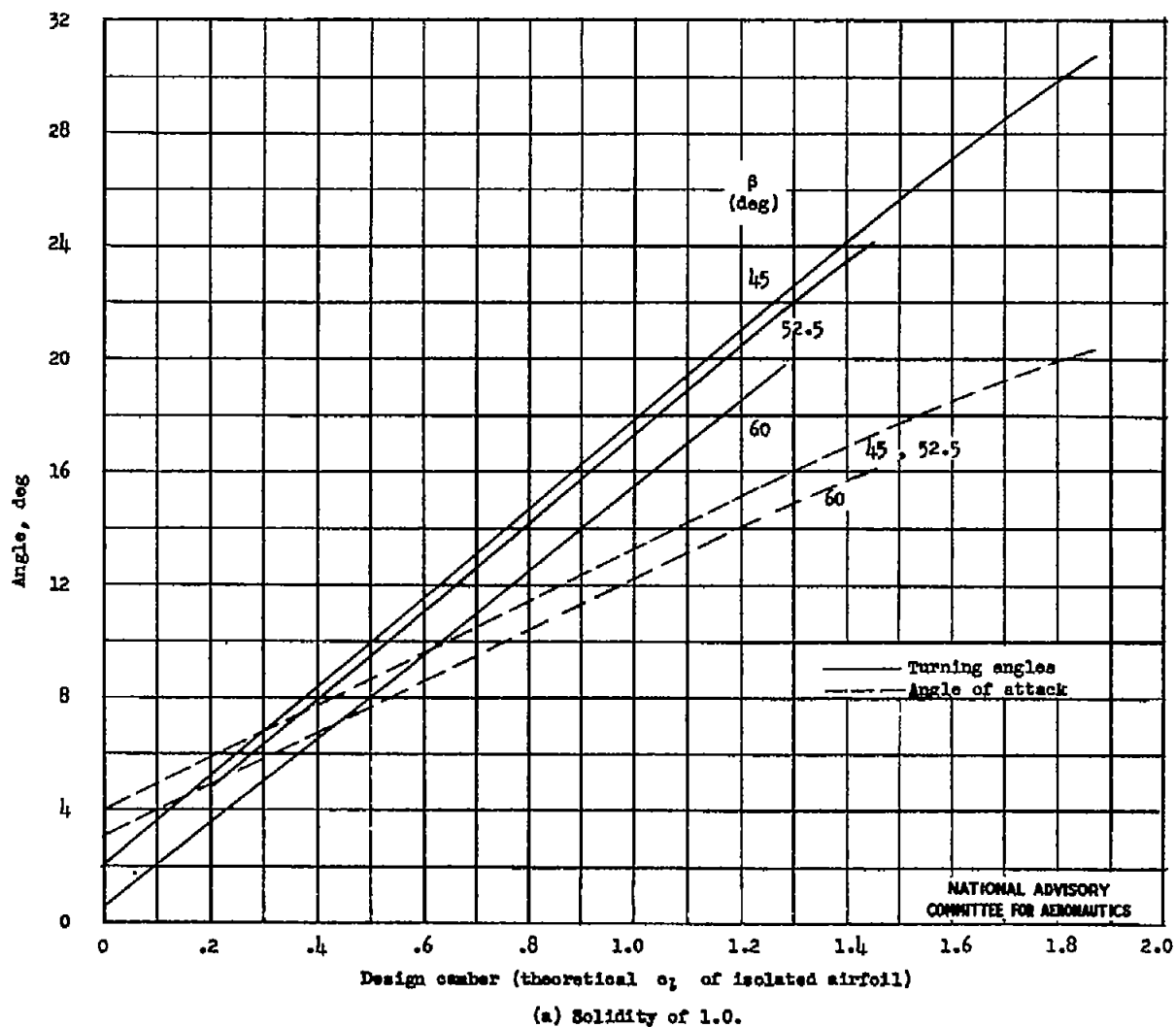
(a) Solidity of 1.0.

Figure 14.- Axial-flow fan and compressor blade design charts
for NACA 65-series blower blades.

Design camber (theoretical c_l of isolated airfoil)
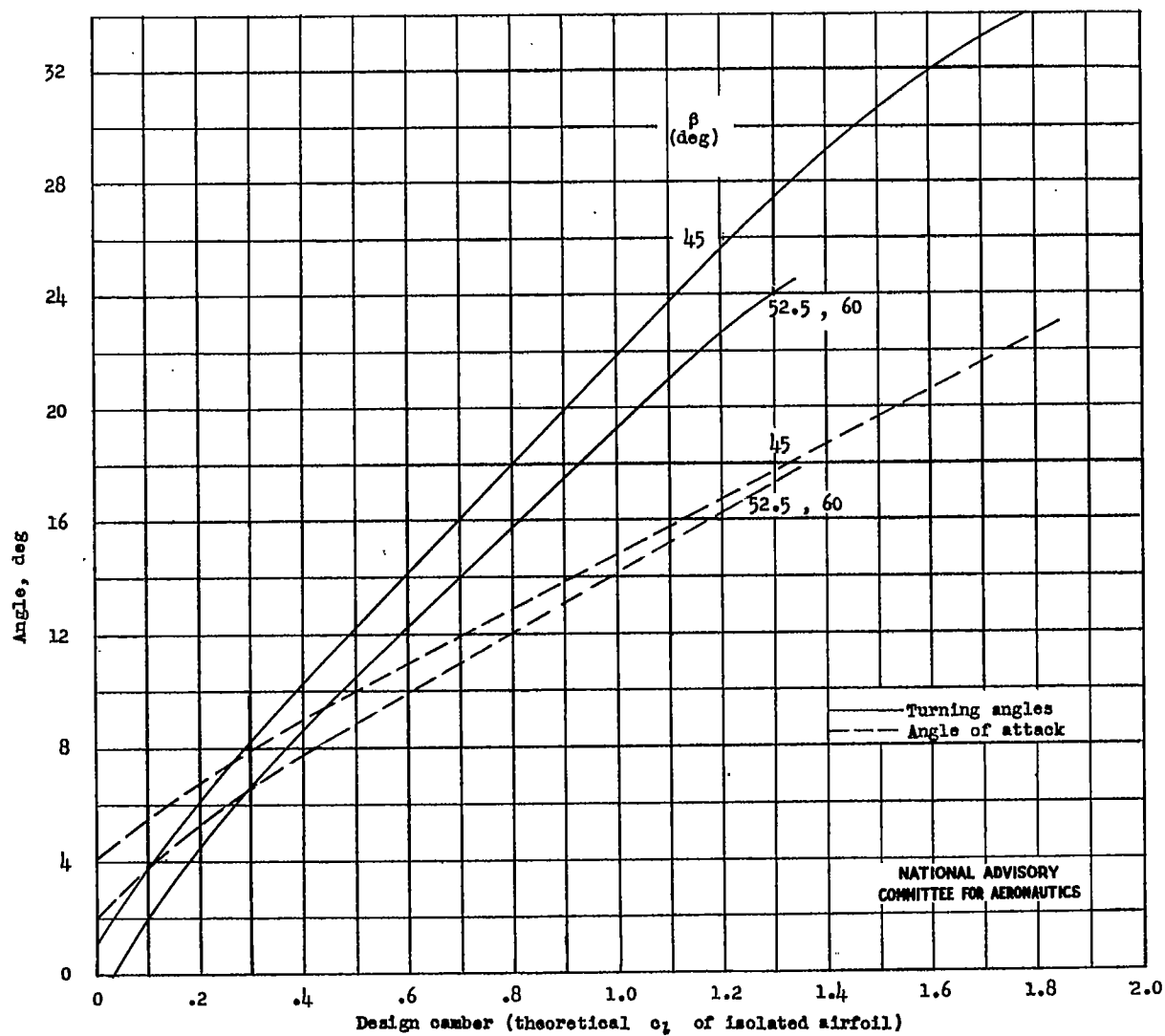
(b) Solidity of 1.5.

Figure 14.- Concluded.

Fig. 15   NACA TN No. 1271
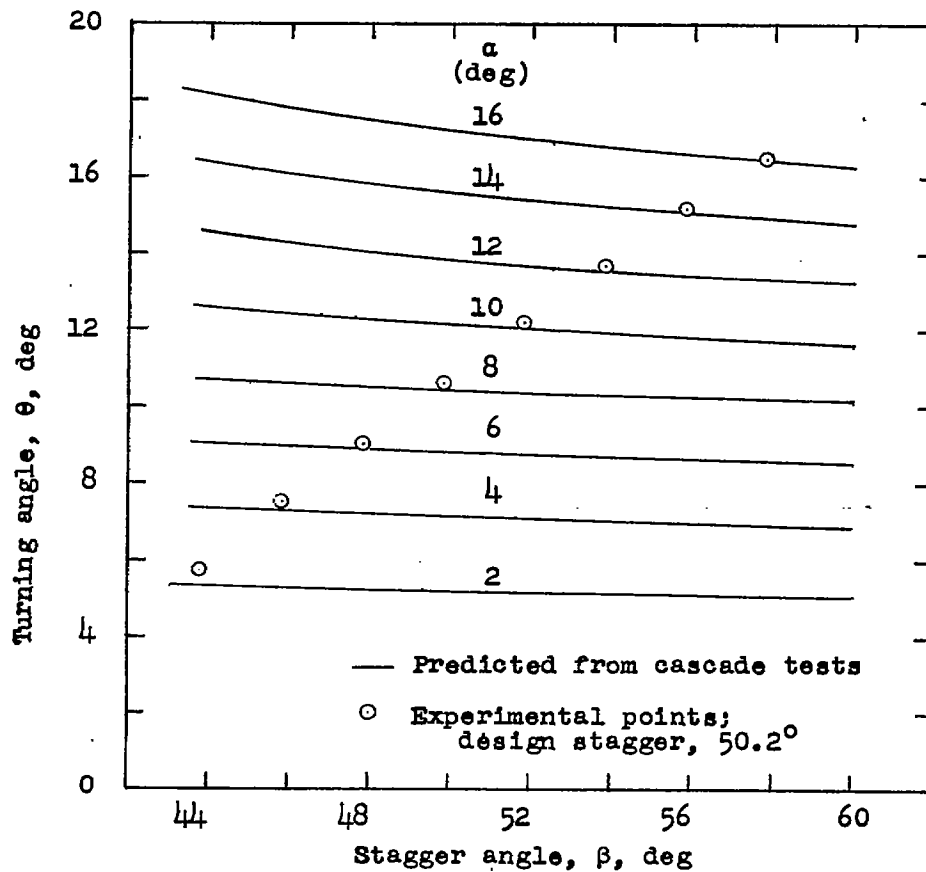

Figure 15.- Variation of turning angle with stagger
  predicted from cascade tests and comparison with
  values obtained in a test blower. NACA 65-710
  blower blades; $\sigma = 1.0$.

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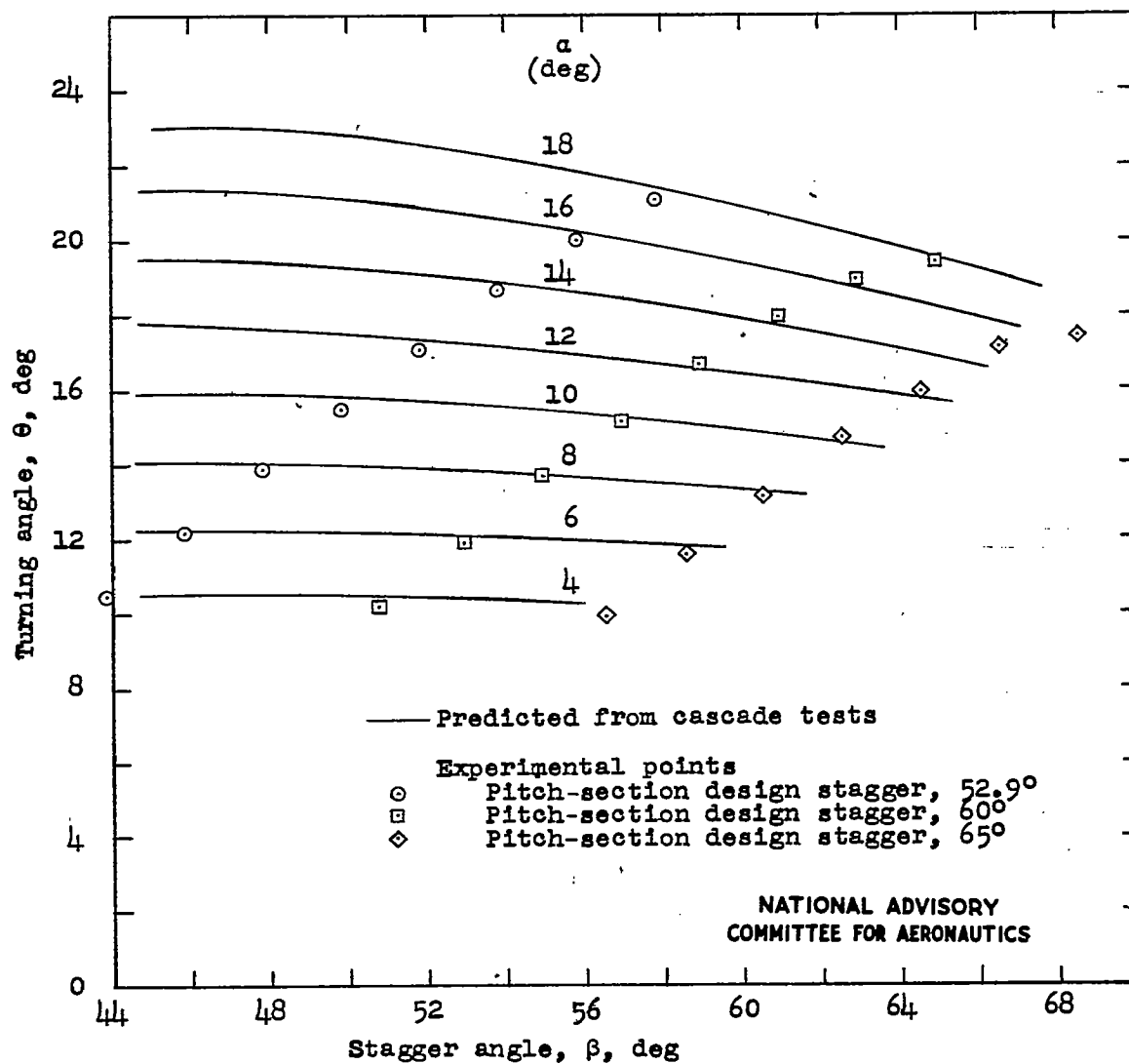COMMITTEE FOR AERONAUTICS

Figure 16.- Variation of turning angle with stagger predicted from cascade tests and comparison with values obtained in a test blower. NACA 65-(11)10 blower blades, $\sigma = 1.0$.